PERFORMANCE OF ASPHALT CONCRETE PAVEMENTS PRODUCED BY THE DRUM MIXER PROCESS

DOUGLAS JOHAN HOLEN

1975

Performance of Asphalt Concrete Pavements Produced by the Drum Mixer Process

by

Douglas Johan Holen

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science in Civil Engineering

University of Washington

1975

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES IN APPENDIX

LIST OF FIGURES IN APPENDIX

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to my thesis advisor, Professor Ronald L. Terrel, for his advice, guidance, and encouragement during the preparation of this thesis. Special thanks are also due Professors Albert L. Hoag and William M. Miller, members of my thesis committee.

I am also grateful for the financial support extended my by the Boeing Construction Equipment Company, Incorporated, and for the assistance, cooperation, and financial support extended me by the Highway Departments in Arizona, North Dakota, and Oregon, and the Division of Aviation, Department of Public Works, in Alaska.

Finally, I wish to thank the United States Navy for providing the financial support necessary for my post graduate education, and my wife, Barbara, for providing encouragement and moral support during this past school year.

CHAPTER I

INTRODUCTION

The drum mixer process has been developed to produce asphalt concrete for roadway and airfield pavement surfaces or treated bases. It is designed to replace the familiar batch and continuous mix asphalt plants in some, if not all, applications. The plant is simpler, requires fewer pieces of machinery, costs less to purchase for a given production rate, and purportedly produces a product of equal quality, consistency, workability, and durability to the familiar batch and continuous mix plants.

In the process the asphalt cement is introduced into a dryer drum or "turbulent mass" mixer simultaneously with the graded aggregates and mineral filler. The asphalt concrete is produced in this one unit or piece of equipment, and the need to dry, heat, regrade, store, and transport the hot aggregate is eliminated. The drum mixer is similar in size and exterior appearance to an aggregate dryer. The reduction in equipment reduces the size and cost of a plant for a particular production rate.

Although no exact cost studies are available, most agencies assume that cost savings result from using the plant. Mr. Erling Henrikson, Construction Engineer, North Dakota Highway Department, stated in March, 1975, that he felt the department was "realizing at least $1.00 per ton savings from the dryer drum mixing".(1) He also stated that the factors contributing toward this savings were:

> reduced costs, substantial production increases, and reduced mobilization costs because of the dryer drum portability.(1)

There can be no exact determination of savings, of course, until the asphalt concrete pavements produced by the drum mixer can be evaluated over their design life. It must be shown that the asphalt concrete pro-

duced in the drum mixer is, indeed, as durable as the asphalt concrete produced by conventional batch or continuous mix plants. If these pavements are not as durable, the annual cost of their maintenance will certainly reduce, or perhaps negate, the initial first cost savings in the use of the process.

The object of this study is to evaluate some of the early pavements produced by the drum mixer process to determine if they are, in fact, proving to be as durable as their companion, conventionally mixed asphalt concrete pavements.

CHAPTER II

BACKGROUND

2.1 History

The idea of mixing asphalt and cold aggregate in one step is not new. Mr. Edwin Granley has noted that:

> This process, with minor modifications, was used before the First World War to produce a good share of paving material. They continued in use until the early 1930's and were superceded in favor of road mix or by conventional batch plants.
>
> In 1959 the Asheville Paving Company developed a high volume prototype dryer drum mixer in North Carolina in an effort to produce a less costly mix with penetration grade asphalts. The plant was used to lay experimental sections, but the contractor was not able to convince the State of it's worth.(2)

In 1969 the McConnaughay Company of Indiana introduced and patented a design for a "turbulent mass" mixer. Subsequently, several manufacturers, including Barber-Greene, Iowa Manufacturing Company and CMI, began developing lines of these equipments.

In 1970 Mr. H. N. Shearer developed a similar process, partly out of dissatisfaction with features of the McConnaughay design, and patented it. The Boeing Construction Equipment Company, Incorporated, obtained the license from Pavement Systems, Incorporated, to produce these plants and introduced a line of these equipments in 1973.

The United States patents describing these two processes are:

Table 1. Drum Mixer Patents

U.S. Patent	Holder	Date
3,423,222	K. E. McConnaughay	January 21, 1969
3,832,201	H. N. Shearer	August 27, 1974

These patents are very similar. Both indicate that a rotating drum mixer will be used to simultaneously heat the aggregate and fines, mix or

coat these aggregates with an asphalt or thermoplastic binder, and continously discharge the mixed asphalt paving composition. They differ in the manner in which the aggregate is coated by asphalt or thermoplastic binder within the drum.

In the McConnaughay design, the patent indicates that the binder and water or water and additives will be introduced into the drum through pipes to "form a dispersion in the form of a cloud". (3) This cloud is maintained in the elevated temperatures within the drum mixer and the aggregates and fines are coated by the asphalt binder in this cloud as they are tumbled through it by the action of the blades on the interior of the rotating drum. This dispersed cloud and tumbling aggregate mixture is referred to as the turbulent mass; hence, the name or trademark of the process.

In the Shearer design, the patent indicates that no water dispersed cloud of thermoplastic binder is present. The aggregate is sprayed with asphalt binder and introduced to the drum where a series of flights of blades thoroughly mix the two at elevated temperatures as they travel the length of the drum together.

Production models of these plants have been modified somewhat since these patents were written. Better procedures and designs have been developed through practice.

In this report, the author will refer to both processes as drum mixers unless a specific reference seems warranted.

2.2 Early Projects

The stories of the early projects have been told and retold. To summarize, in 1970 projects were initiated in Washington and Iowa. These projects were successful, and in 1971 additional projects were undertaken in these states. In 1972, projects were completed in Iowa, North Dakota,

Minnesota, and Oregon. The successes of that construction season gave rise to additional trial projects in several other states in 1973. In the 1974 construction season, 15,000,000 tons were produced by the drum mixer process.

This growth was reported to the 20th Annual Convention of the National Asphalt Pavement Association on February 6, 1975, by Edwin C. Granley, Highway Engineer, Federal Highway Administration. Mr. Granley stated:

> You will note.....that fourteen states allow its use on all projects, and the remainder either allow its use on some projects or are actively considering acceptance. Only 13 states still report that no requests for use of the process have been received, and several of these have indicated that the decision has already been made to grant permission.(2)

2.3 Early Research

Research efforts accompanied most of the early projects. Projects in Iowa, Minnesota, North Dakota, and Washington were monitored by the Federal Highway Administration. Others were monitored closely by highway departments, public works agencies, and owners.

The first project in Washington was initiated by the Shearer Construction Company in a private development for Pope and Talbot Properties, Incorporated, at Port Ludlow, Washington, in January, 1970. Approximately five miles of two lane roadway consisting of 1-1/2 inches of Class F mix (Washington state specifications) over 3 inches of asphalt treated base were constructed. A total of approximately 14,000 tons of asphalt was produced by a dryer drum mixer designed and built by the Shearer Construction Company of Everett, Washington. In reviewing this project, Mr. W. L. Allen, Jr., Area Engineer, Federal Highway Administration, concluded:

> Based on the limited initial evaluation, recovered asphalt penetration was not reduced below acceptable limits; mixtures of suitable strength and durability can easily be obtained; and with suitable controls, asphalt mixtures meeting all normal requirements can be produced routinely.(4)

In a report to the National Asphalt Pavement Association in January, 1972, Mr. James L. Ziegler, Kenyon Construction Company, Des Moines, Iowa, described the early use of a turbulent mass mixer to produce asphalt concrete in Iowa. The plant was obtained under license from the K. E. McConnaughay Company in February, 1970, and placed in operation in July. Approximately ten miles of resurfacing were complete in 1970, and six more projects totaling 42,158 tons of base and 22,768 tons of surface course were completed in 1971. Mr. Ziegler noted that these projects were closely monitored and that the asphalt concrete produced was of good quality in all respects. He also noted that "the plant has been taken down, moved 150 miles, assembled, and recalibrated within three days".(5)

In the summer of 1971, two projects were undertaken in Washington, one at Hartstone Point near Shelton and another on Weyerhauser property near Longview. Both of these projects were completed by the Shearer Construction Company using a dryer drum mixer of their own design. Research accompanying these projects was documented for the Federal Highway Administration, Washington Division, by R. L. Terrel, University of Washington, and Emory S. Richardson, Federal Highway Administration. The authors offered the following general conclusions:

1. The dryer-drum asphalt mixing process produced (if under controlled conditions) mixtures capable of meeting most if not all requirements for high quality material.

2. In terms of high production with smaller equipment cost, it may be initially best suited to asphalt treated base. However, it would appear that it is also capable of producing normal high quality surfacing material.

3. In view of the process' potential, considerable cost savings could result due to reduced equipment and fuel requirements.

4. Visual observations indicate air pollution from the exhaust stack is reduced. The plant could probably

meet many current regulations with no primary dust collector. For some material combinations, one of the simpler dust collectors may be required to meet the rigid limits. This is further supported by the retention of aggregate fines in the mixtures.

5. Quality control must be achieved through automatic interlocked plant controls for acceptance to be forthcoming on a general basis.

6. The process can handle aggregates with water contents ranging from 0 to ten percent.

7. Mixes may be produced over a range of temperatures using paving grade asphalts without detrimental hardening of the asphalt.

8. Laydown and compaction temperatures consistent with the lower range of mixing temperatures may be practicable only if sufficient moisture (say 1-3%) is present in the mixture to aid in compaction process.

9. By following conventional construction practices, adequate mixture properties such as stability, cohesion, density, and voids can be achieved.

10. It appears that the asphalt in the mixtures produced by this plant are hardened less than, or no more than, mixtures from conventional plants.

11. Normal compaction density can be achieved at lower than normal temperatures, apparently because of the moisture retained in the mixture at the time of laydown.

12. Both observations and tests indicate the aggregates are well coated during the mixing and laydown operations and there is no tendency for later stripping.(6)

On November 28, 1972, Mr. Edwin C. Cranley, reviewed the drum mixer projects which were completed in the summer of 1972 before the Subcommittee on Construction of the American Association of State Highway Officials. He stated that:

> The first study was conducted in North Dakota on the bitumious hot mix produced in a Shearer-designed dryer. This 10 by 40 ft. butane-propane-fired dryer was used to produce mixes for overlaying and widening an existing pavement on State Route 1 north of Lakota. The surfacing mixture consisted of 200/300 penetration grade asphalt and 5/8 in. maximum size dense-graded crushed-gravel aggregate. On two additional short sections,

mixtures containing 85/100 and 120/150 penetration grade asphalt were laid to evaluate their performance. On each section, one-half of the mixes were produced at 200°-220°F and the other half at higher temperatures. Normal procedures were used for compacting these sections. Production rates varied from 240 to 400 tons per hour.

The second study, conducted in Iowa, was on a 9 by 36 ft. Cedarapids turbulent mass process dryer. This unit was producing base material at 190°F and surfacing material at 260°F for an Emmet County project near Estherville. During the observation period, 5/8 in. maximum size crushed gravel and 120/150 penetration grade asphalt were used for the base mixture and 85/100 for the surfacing course. A butane-propane mixture was used for fuel and a proprietary chemical agent was added to aid in coating the aggregate. Production varied from 275 to 340 tons per hour.

The third study was made on a 9 by 32 ft. fuel-oil-fired Barber-Greene dryer at Olivia, Minn. During the first phase of this study, the plant was used to produce an overlay material for city streets in Olivia. The mix was a blend of 3/8 in. maximum-size taconite aggregate and 120/150 penetration-grade asphalt and was mixed between 310° and 360°F. For the second phase, 5/8 in. maximum-size crushed gravel aggregate and 120/150 penetration-grade asphalt were used for surfacing Route 21 in Renville County. The temperature of the mix produced at the plant in this phase was 230°F. The production rate for both mixes was 200 tons per hour.

Evaluation of the dryer-drum process was directed primarily toward obtaining the answers of two questions concerning quality:

1. Was the mixture being harmed by exposure to direct flame in the dryer?

2. Would the equipment consistently produce a uniform product?(7)

He concluded that:

The asphalt in the mixes produced by the dryer-drum operation was not prematurely hardened...uniformity of asphalt content and aggregate gradation were within tolerable limits ...specified densities were achieved by compaction...dust emissions appeared to be within tolerable limits with this process...

While the Federal Highway Administration studies have not provided all answers regarding quality, they have shown conclusively that a quality product can be produced by conventional plants.(7)

In November, 1974, the California Department of Transportation, in cooperation with the Federal Highway Administration, published a report which described three projects in which a drum mixer was used to produce the asphalt concrete in that state. The projects which were completed in the fall of 1973 included two California State Highway projects and one U. S. Forest Service project. Over 100,000 tons of asphalt concrete were produced in these projects.

The authors stated that:

> Because of the potential benefits of this new method, it is of importance to evaluate the asphalt concrete produced by the dryer-drum and determine its performance in the field. Accordingly, this research effort was designed to answer the following questions:
>
> 1. Is the mixture being harmed by the exposure to the asphalt to the conditions within the dryer-drum mixer?
>
> 2. Will the plant equipment produce a consistently uniform product?
>
> 3. Will the combination of lower mix temperatures and higher moisture contents present any construction or performance problems?
>
> 4. Is the mix produced durable under field conditions?(8)

They concluded that:.

> At this stage of the study, the following general conclusions can be drawn about the observed dryer-drum mixing method of asphalt concrete production:
>
> 1. The A.C. mixture tested did not appear to be harmed by the exposure of the asphalt in the dryer-drum mixer. However, unconsumed burner fuel (diesel) apparently contaminated the asphalt and softened it, or "cut" it back, excessively. Thus burner efficiency may be critical to the production of a quality mix.
>
> 2. The dryer-drum mixing plant produced A.C. mixture of a uniformity that matches the mean capability of conventional plants. Both the asphalt content and the aggregate gradation variation remained within reasonable limits.
>
> 3. Relative compactions obtained were marginal to substandard. This low compaction could be attributed

to one or more of the following three factors: (a) improper operation of the vibratory roller, (b) lower than conventional mix temperatures, and (c) lack of the extra remaining moisture anticipated in the dryer-drum process.

4. An air pollution control device was necessary in addition to the cyclone dust collector on the one plant tested to date. The water-scrubber added to the stack was effective, but necessitated the development of a settling pond for the effluent.

5. The A.C. pavement appears to be providing generally satisfactory service at this time with no rutting or major defects in evidence.(8)

These are by no means the only early projects on which the drum mixer was employed and which were closely scrutinized to determine the quality of the product produced. Similar projects were initiated in Oregon, Colorado, Arizona, Utah, Michigan, and Alaska about the same time.

CHAPTER III

INVESTIGATION OF SEVERAL EARLY DRUM MIXER PROJECTS

3.1 Procedure

During the months of June and July, 1975, the author visited four states in which early drum mixer projects were completed. The states were North Dakota, Arizona, Oregon, and Alaska. With the help and cooperation of the highway or public works agency responsible, one early project in each of these states was chosen for investigation. This investigation was conducted in two parts. First, any distress present in the pavement surface of the project investigated was noted and photographed. Second, pavement cores were obtained from selected locations on each project for laboratory evaluation. These cores were used in laboratory tests conducted at the University of Washington and Washington State Department of Highways Materials laboratory.

The tests which were completed are as follows:

1. Marshall Stability and Flow. ASTM D1559

2. Specific Gravity of Compacted Asphalt Mixtures. Washington State High Department Test No. 704C (similar to AASHO T230)

3. Rice Vacuum Pycnometer Method for Measurement of Maximum Density of Bituminous Mixture, Washington State Highway Department Test No. 705A (similar to ASTM D2041)

4. Modified Abson Recovered Penetration Test. Washington State Highway Department Test No. 201A (Similar to ASTM D-5)

5. Asphalt Content by Hot Solvent Extraction, Washington State Highway Department Test No. 709A (similar to ASTM D2172)

6. Marshall Stability after 24 Hour Soak @ 140°F. (similar to ASTM D1075)

7. Dry Sieve Analysis. AASHO T27.

It was hoped that some indication of the servicability of the asphalt concrete produced by the drum mixer in these early projects could be

measured by these tests and that some conclusions could be drawn as to whether or not the asphalt concrete so produced was as durable as asphalt concrete produced in a conventional plant.

Admittedly, there are more refined tests available to test the strength of an asphalt concrete mix and the aging or hardening of the asphalt in the mix than the Marshall Stability and Standard Penetration tests. However, the standard penetration test was used in the early monitoring of all of these projects, and the Marshall method of mix design was used in two of the four, Alaska and North Dakota. It was felt that these tests should be used again so that the early data and the present findings could be compared directly.

The Marshall stability tests were used to gauge the strength of the aged asphalt concrete from each of the projects. The specific gravity tests were used to measure the relative densities of the aged asphalt concrete in-situ. The recovered penetration tests were used to gauge the aging or hardening of the asphalt in the various mixes; i.e., to determine if the asphalt in these mixes is hardened at the same rate as asphalt in conventionally mixed asphalt concrete. The asphalt extraction tests were performed on the various mixes to complete the data picture and to help resolve any anomaly that might arise.

The Marshall stability test after a 24-hour soak at 140°F was used to identify any stripping problems that might exist in these early drum mixer mixes. Although not a standard, the test would indicate whether or not the higher mixing moisture contents inherent in the drum mixer process affected the bonding of the asphalt and the aggregate. If they had, the Marshall stability values obtained after the 24-hour immersion would be much lower than the values obtained in the standard test.

The gradation analyses were compared with the original date to ensure that representative samples were obtained.

3.1.1 Surface Condition Survey

The original intent of this study was to conduct a Pavement Condition Survey in the field in which all of the various forms of surface distress were quantified and a measure of the total surface condition obtained. However, each of the projects visited were in much better condition than anticipated, and the surface distresses noted were few. It proved simpler to note them, record their frequency or location, photograph them, and complete the survey from these photographs. Many of the photographs used in this survey are included in Appendix B. In addition, a surface map showing the crack patterns of the east-west runway at the Nome Airport in Alaska is included in Appendix C.

3.1.2 Sampling and Laboratory Procedure

Two sampling locations were selected at each project visited. Six cores, approximately four inches in diameter, were taken at each of these locations. The six cores were taken approximately one foot apart. A photograph of a typical sampling location is shown in Appendix B.

The testing noted above was conducted in the following manner: First, two cores were selected from each sampling location and dried in the oven at 70°C until they reached a constant weight. This is the basis of the moisture content determination cited in this report. Although this is not a standard test, it does give an indication of the moisture in the samples. Some of the cores were taken by wet coring procedures, others were taken in the rain or after very wet climatic conditions. A more exact determination of moisture content would have been unreliable and would have been a destructive test rendering the cores unusable for subsequent tests.

Next, two cores were sawn to provide a biscuit approximately two and one half inches thick and tested for Marshall stability and flow. In sawing these specimens, care was taken to remove any aggregate surface treatment

(North Dakota) or to cut away any portion of the core that might be affected by other penetrating surface treatments (Arizona). In some cases the lift thickness used in construction precluded using a 2-1/2 inch thick specimen and a thinner one was used; e.g., a 1-1/2 inch specimen was obtained from both the bottom and top lifts contained in each core taken from the runway at the Nome Airport.

Once the Marshall tests were completed, the specimens used in the test were sent to the Washington State Highway Department Materials Laboratory for recovered asphalt penetration, recovered asphalt content, and gradation analysis.

The two cores which were used in the moisture content determination were then used to determine the specific gravity of the compacted asphalt mixture and to determine the maximum density of the mixture by the Rice Vacuum Pycnometer Method.

Subsequently, these cores together with the Marshall specimens were used for additional asphalt content determinations and gradation analyses.

After the first set of recovered penetration test data was received from the Washington State Highway Department Materials Laboratory, four additional cores, one from each project, were sent to the laboratory for additional recovered penetration tests.

The final cores were trimmed for use as Marshall specimens as described before but were placed in a 140^{o}F water bath for 24 hours before testing. This test was used to determine the retained strength of the compacted asphalt concrete mixtures under extreme conditions which would lead to stripping.

3.2 Nome Airport

On June 19, 1975, the author visited the Nome Airport in Nome, Alaska. The runways, taxiways, and aprons had been reconstructed by the Burgess

Construction Company, Fairbanks, Alaska, during the 1973 and 1974 construction seasons. The contractor used a Boeing manufactured 10 by 40 drum mixer. A typical runway section included a 3 inch bituminous surface course placed in two lifts over a 9 inch crushed aggregate base course and an 11 inch subbase. The taxiways were similar except that a 24 inch subbase was required. The average temperature of the mix at the paver was 238°F.

The east-west runway was completed in August, 1973. It was approximately 150 feet wide by 7,400 feet long. Since this was the oldest section of the runway, the cores were taken here. However, pictures were taken of the surface of the north-south runway, completed in 1974, to compare the surface conditions of the two runways.

3.2.1 Job Mix Formula

The job mix formula for the asphalt concrete specified that a 6.00 percent 120-150 penetration grade asphalt cement together with a blend of 51 percent course aggregate and 49 percent fine aggregate by weight should be used. This blend would produce the gradation shown in Table 2. This formula was prepared for the contractor by R & M Engineering Consultants, Fairbanks, Alaska.

3.2.2 Construction Test Results

The contractor was able to maintain a mean compaction of 95.2 percent "Laboratory Marshall" density in place throughout the job as verified by 94 cores taken after paving. The asphalt content of the mix averaged 6.2 percent. The mean value of the Marshall stabilities of the mix samples was 1589 pounds, and the flow varied between 8.3 and 13.7 hundredths of an inch. The results of the sieve analysis taken on thirty samples is shown in Table 2 and is compared to the specifications for the job.

3.2.3 Pavement Condition Survey

The only sign of pavement distress noted was transverse cracks on regular spacing of about two hundred feet. These crack patterns were mapped and this map, together with photographs of the surface condition, are included in Appendices A and B.

It was interesting to note that the cracks occured at regular intervals and extended through the asphalt concrete into the subgrade below. Cracks were inevitably present over buried utilities. The author believes that the cracks were either thermal or reflective, the reflective cracks occurring where the presence of buried utilities melted the permafrost, weakening the subgrade. The cracks in the 1973 pavement were noticeably wider than those in the 1974 pavement. Photographs in Appendix B illustrate this phenomenon.

3.2.4 Laboratory Test Results

Six cores were taken at each of two locations on the east-west runway. The data from the laboratory investigation performed at the University of Washington and Washington State Department of Highways Materials Laboratory together with the average construction data is shown in Tables A-1, A-2, and A-3 in the appendix.

The average Marshall stability obtained in 1973 from compacted mix samples was 1589 pounds. The average value for the stability of the cores obtained in 1975 was 1604 pounds. The average stability of the cores which were soaked in the water bath for 24 hours at 140°F before testing was 1379 pounds or 86 percent of the standard value obtained.

No recovered penetration tests were taken at the time of construction, so it is uncertain what the penetration of the mix was when the pavement was new. The average recovered penetration value obtained in 1975 was 51.

3.3 Safford-Springerville Highway, Arizona

On June 27, 1975, the author visited UNIT I of the Nutrioso-Alpine Section of the Safford-Springerville Highway near Alpine, Arizona. This highway had been paved in September, 1973, by Peter Kiewit and Sons. A Boeing manufactured drum mixer was used to produce the asphalt concrete.

A typical section included 7 inches of asphalt concrete placed over a standard base. The section paved was approximately 4.63 miles long.

3.3.1 Job Mix Formula

The job mix formula called for a mix of 7 percent of 85-100 penetration grade asphalt cement mixed with aggregate of the gradation shown in Table 3.

3.3.2 Construction Test Results

The quality control tests for this project included 152 samples in which the percentage of asphalt was recorded. The mean of this sample was 6.9 percent; the standard deviation was 0.5 percent. Other parameters measured included the gradation of the aggregate and penetration of the asphalt. The gradation of the asphalt concrete was obtained from samples obtained after mixing, and the penetration of the asphalt was measured on samples obtained prior to mixing.

Data describing the overall gradation of the mix produced by the drum mixer are shown in Table 3. These values were also computed from a sample size of 152 observations. The penetration of the asphalt used in the mix varied from 94-102. Apparently, recovered penetrations were not obtained, so no measure of the aging of the asphalt during the mixing process was noted on this project.

3.3.3 Pavement Condition Survey

The only sign of pavement distress noted was flushing in the wheel paths. Pictures were taken at both sampling locations and are included in

Appendix B. It should be noted that a MC 250 asphalt cement "flushcoat" was applied to the surface of the roadway at the rate of 0.10 gallon per square yard following construction. The material in the flushcoat could have contributed to the flushing noted.

3.3.4 Laboratory Test Results

The data from the laboratory investigation conducted at the University of Washington together with the average construction data obtained by the Arizona Department of Highways is shown in Tables A-4 and A-5 in the appendix.

The Arizona Department of Highways does not use the Marshall method of mix design. However, the Asphalt Institute (9) cites a minimum design stability of 750 for highways with heavy traffic. The value obtained in the laboratory at the University was 1409, The value for the stability after 24 hours in the water bath at 140°F was 1357 or 96 percent of the original value, indicating that prolonged soaking does not materially affect this mix. The recovered asphalt penetration averaged 53 percent of the penetration of the asphalt before mixing.

3.4 Estacada-Eagle Creek Section of Clackamas Highway, Oregon

On July 1, 1975, the author visited the Estacada-Eagle Creek section of the Clackamas Highway in Oregon. This project had been completed in November of 1972 by the Page Paving Company. The company had used a Shearer Process, Incorporated, 9 by 36 dryer drum to produce 53,000 tons of Oregon State Class "B" mix in paving approximately 5.8 miles of highway. This material was placed over a previously placed cement treated base.

3.4.1 Job Mix Formula

The job mix formula called for 6 percent 120-150 penetration grade asphalt cement blended with the aggregate gradation shown in Table 4. This

material was to be compacted to 92 percent of Oregon design density.

3.4.2 Construction Test Results

The temperature behind the paving machine averaged 190°F. The moisture content of the mix behind the paver averaged 2.1 percent. The original average penetration of the asphalt content was 125. The reclaimed asphalt penetration averaged 96, and the TFOT residuo averaged 76. The asphalt content of the mixture produced was 6.1 percent. Thc average gradation of the mixture produced is shown in Table 4. In general the contractor was able to remain within specifications with this equipment.

3.4.3 Pavement Condition Survey

As with the other projects, very little pavement distress was noted. The only distress observed was raveling in the wheel paths. This is shown in the photographs in Appendix B. Mr. J. Wilson, Jr., Assistant Materials Engineer, Oregon State Highway Division, noted that this highway receives heavy studded snow tire service in the winter and that the raveling noted is probably caused by this traffic.

3.4.4 Laboratory Test Results

The results of the laboratory testing conducted at the University of Washington and at the Materials Laboratory, Washington State Highway Department, together with the construction data obtained by the Oregon State Division of Highways in 1973 is shown in Tables A-6 and A-7 in the appendix.

The Oregon State Division of Highways does not use the Marshall method of mix design. However, the average value for the Marshall stabilities of the cores obtained was greater than that recommended by the Asphalt Institute (9) for highways with heavy use. Cores were taken from both the outer wheel path and from less trafficked sections of the pavement. The cores taken in the wheel path exhibited higner stabilities and higher bulk specific gravities than the other cores.

The Marshall stabilities of the cores taken from both of these locations, which were subjected to a 24 hour soaking period at 140°F before testing, were unchanged from the Marshall stabilities obtained in the standard test after a thirty minute soaking period.

The average recovered penetration value for the asphalt in the cores taken from the outer wheel path at station 1121+00 was 78, or 81 percent of the recovered penetration value obtained at this point during construction in 1973.

3.5 State Route ONE, Lakota, North Dakota

On June 25, 1975, the author visited the site of an early drum mixer project in North Dakota. This project, often referred to as the Lakota Test Road in the literature, had been the first state highway project completed using a drum mixer in North Dakota. Completed in July of 1972 by the Northern Improvement Company, Incorporated, of Fargo, North Dakota, this project called for a 2 inch overlay on approximately 28 miles of the highway. In one section, 200-300 penetration asphalt cement was used. In another, 120-150 penetration asphalt cement was used. There were also sections of the project where 85-100 penetration asphalt cement was used and sections where a variety of base courses were installed as a test section. However, cores were not obtained in these locations.

3.5.1 Job Mix Formula

The job mix formula called for a blend of North Dakota Class 25 aggregate and 6.4 percent asphalt cement in the section where the 120-150 penetration asphalt was specified, and the same aggregate blend and 6.6 percent asphalt cement in the section where the 200-300 penetration asphalt was specified.

3.5.2 Construction Test Results

The average recovered asphalt content in the section where 200-300 penetration asphalt cement was used was 6.3 percent. The average recovered

penetration for this section was 179. The TFOT residue was 135 for this material.

In the section where the 120-150 penetration asphalt cement was used, the average recovered asphalt content was 6.3 percent. The average recovered penetration value for this section was 114. The TFOT residue value was 79 for this material. The average gradation for both sections is shown in Table 5 and is compared to the project specifications. As can be seen, the contractor was able to meet gradation specifications with this equipment.

3.5.3 Pavement Condition Survey

A surface treatment had been applied to the pavement in the interim since construction. Mr. R. Peterson, Research Engineer, North Dakota Highway Department stated that this is done as a matter of course in North Dakota to improve night visibility and skid resistance and does not indicate that any particular surface problems were encountered which had to be remedied by this action. The only signs of pavement distress noted were transverse and longitudinal cracks. To describe these cracks, crack counts were taken 500 feet ahead and back of each sampling station. The results of these counts are shown in Table 6.

3.5.4 Laboratory Test Results

The data from the laboratory investigation conducted at the University of Washington, together with the data obtained by the North Dakota Highway Department at the time of construction in 1972, and the data from cores obtained in 1974 is shown in Tables A-8 and A-9 in the Appendix.

The average value for the stability of the cores recovered from the region where 200-300 penetration asphalt was used was 1196. This is greater than the mix design value of 1140 pounds. No record is available for the stability of the mix actually produced. The corresponding value for the

stability of the cores recovered from the region where 120-150 asphalt was used was 1036 pounds. The Marshall stabilities of the cores from both of these locations, which were subjected to the 24 hour soaking period at 140°F before testing, were unchanged from the Marshall stabilities obtained in the standard test.

The recovered penetration obtained from the cores taken from station 404+00 where 120-150 penetration asphalt had been used averaged 77 or 59 percent of the original penetration of this material. The recovered penetration obtained from the cores taken from station 276+00 where 200-300 penetration asphalt was used averaged 233. The average penetration for the asphalt recovered from mix samples taken in this region at the time of construction in 1972 was 179. The North Dakota Department of Highways obtained additional cores from this project again in 1974, and the average recovered asphalt penetration for the region where 200-300 penetration asphalt had been used was 114. Therefore, the author feels that the cores taken in 1975 from this location were contaminated in some way, and the recovered penetration value obtained from these cores is not indicative of the condition of the aged asphalt in this section.

CHAPTER IV

EVALUATION OF TEST RESULTS AND PAVEMENT CONDITION SURVEY

4.1 Evaluation of Laboratory Test Data

The Marshall Stability value for all of the pavements sampled are reasonable. In those states where the Marshall method of mix design was used originally, the stability values of the pavements investigated have endured.

The mean of the stabilities obtained at the time of construction in Nome, Alaska, in 1973 was 1589 pounds. The mean of the stabilities obtained in 1975 was 1604 or 101 percent of the original value.

The design value for Marshall stability prepared by the North Dakota Department of Highways for State Route ONE near Lakota, North Dakota, was 1140 pounds. The average stability value obtained in the laboratory in 1975 from cores taken from the section where 120-150 penetration asphalt was used was 1195 pounds or 105 percent of the design value. The value obtained from cores extracted from the pavement where 200-300 penetration asphalt was used was 1036 pounds or 91 percent of the design value.

In those states where another method of mix design was used or no original or design Marshall stability was available, the stabilities obtained in 1975 were compared to the minimum design standard recommended by the Asphalt Institute for highways with heavy use. The average Marshall stability value for the cores obtained from the Safford-Springerville highway in Arizona was 1407 pounds or 188 percent of the Asphalt Institute design standard. The average Marshall stability for the Estacada-Eagle Creek section of the Clackamas Highway in Oregon was 1548 pounds or 206 percent of the Asphalt Institute standard.

Cores from all of these projects were also immersed in water at 140°F for 24 hours and tested for Marshall stability. The Marshall stabilities obtained after this soaking period were compared to the stabilities obtained in the standard test.

In the cases of the specimens obtained from Nome, Alaska, the Marshall stability obtained after the soaking period was of 86 percent of the Marshall stability obtained in the standard Marshall test. Similarly, the Marshall stability value of the specimens from Arizona obtained after soaking was 96 percent of the stability obtained in the standard test. The Oregon and North Dakota specimens exhibited a stability equal to 100 percent of the standard. A similar test, ASTM D1075, is used by several highway departments to gauge the effect of water on the mix design being considered. The minimum retained strength allowed is often 70 percent.

The average recovered penetration of the asphalt extracted from the cores obtained from the various projects, the original penetration of the asphalt used in these projects, and the percent decrease in penetration of the asphalt recovered from each of the projects is shown in Table 8.

Regretfully, the exact original penetration of the asphalt used in the east-west runway of Nome Airport, Nome, Alaska, is not known; and the penetration of the asphalt recovered from the cores taken at station 404+00 in North Dakota does not seem reasonable (too high).

Traxler and Shelby (10) have shown data indicating that the average decrease in penetration at 77°F of seven pavement sites in Texas after two years in service was 60 percent. The subjective rating of these pavements varied from excellent to good. As can be seen in Table 7, the decrease in penetration of the asphalt in the Arizona pavement, which also has been in service for two years, is only 47 percent, and the decrease in penetration of the asphalt in the North Dakota section sampled in November, 1974, by

the North Dakota Department of Highways, in service for 26 months, is only 55 percent.

Parr and Serafin (11) reported average actual penetrations and percentage of original penetration results of recovered asphalts from six sections of the Michigan test road. The average penetration of the six sections at 29 months age was 62 percent of the original and at 40 months was 54 percent of the original. Table 7 indicates that average penetration of the North Dakota section at 36 months was 59 percent of the original, and the average penetration of the Oregon section at 35 months was 62 percent of the original.

4.2 Pavement Condition Survey

In this section an attempt will be made to quantify or provide a numerical rating for each of the highway pavements observed based upon the photographs taken at the time of sampling. The scheme used will be the Pavement Condition Survey described by LeClerc and Marshall (12). The computations involved in this survey are outlined below.

> In the analysis of rating for a section of pavement separate determinations are first made to establish numerical values for the quality or ride and for the degree of pavement distress. The numerical rating for the ride is that value found when ten times the ride score is subtracted from 100.
>
> The numerical rating for the pavement distress is determined by subtracting from 100 the sum of the numerical values for the defects noted....The final rating of the pavement is determined from the formula:

$$R_R = G_R \times G_D$$

where $G_R = 100 - (10 \times \text{Ride Score})$

$G_D = 100 - \text{Defect Deducts}$

and $R_R = \text{Road Rating}$ (12)

To uniformly compare the riding quality of pavements located in Oregon, Arizona, and North Dakota would be an expensive and difficult task. Generally

in this type of survey, a single vehicle or ride meter is used to gauge the riding quality of each of the pavements surveyed. This was impossible. Instead, a subjective value was assigned to the riding quality of each of the pavements investigated based upon the author's repeated travels over these pavements in whatever vehicle was available. A ride score of 1 or 2 on a scale of 10, where 0 is excellent and 9 is poor, was assigned. In the opinion of the author, the Oregon, Arizona, and one section of the North Dakota pavements rated a ride score of 1. The other section of the North Dakota pavement rated a ride score of 2. The defect deductions were easier to quantify. The photographs were studied, and the extent of the distress was estimated. Pavement defect deductions were then taken from the table provided in reference (12) and deducted from 100 to obtain a value for G_D.

In the case of the Safford-Springerville Highway in Arizona, a ride score of 1 resulted in a G_R of 90. The only sign of distress noted was slight flushing over approximately 15 percent of the highway. The negative value assigned to this defect was 5. The G_D assigned was 95 and the final road rating was 93.

A G_R of 90 was also assigned to the Estacada-Eagle Creek section of the Clackamas Highway in Oregon. The only sign of pavement distress noted in this highway was slight raveling over 16-35 percent of the area of the highway. The negative value assigned to this defect was 10 which resulted in a G_D of 90. The final ride rating for this section was 90.

The Lakota Test Section in North Dakota was divided into two sections for the purposes of this investigation because the severity of the principal pavement distress noted varied markedly between the sections where 120-150 penetration asphalt and 200-300 penetration asphalt were used.

The section of the highway where 200-300 penetrations asphalt was used was given a ride rating of 1. This resulted in a G_R of 90. The pavement

distresses noted were 1/8 inch to 1/4 inch wide transverse cracks occurring four times or less in one station. Longitudinal cracks were also present. The G_D for this section was 92. The final road rating was 91.

The section of the highway where 120-150 penetration asphalt was used was given a ride rating of 2 resulting in a G_R for this section of 80. The transverse cracks in this section occurred on the average of 5-9 per station, and the G_D assigned was 91. The final road rating for this section was 85.

A road rating was not computed for the Nome Airport. The surface condition of the pavement there was excellent. The only sign of distress noted is outlined in the preceding chapter and shown in Figure C-24 in the appendix.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

The purpose of this study was to evaluate four of the early construction projects in which the drum mixer was used to produce the asphalt concrete. This evaluation was conducted in two parts. First, a pavement condition survey was made in which the distress present in these pavements was noted and recorded. Second, cores were taken and subjected to laboratory tests where the stability, hardness, and stripping susceptibility of the aged asphalt concrete in each of these pavements was measured. The results of that investigation are shown in Table 8.

5.2 Conclusions

Testing indicates that the mix produced in each of these projects has remained stable. Each of the Marshall stability values recorded is within tolerable limits. Furthermore, the stabilities of these mixes were not markedly reduced when tested after a 24 hour immersion at 140°F. This indicates that the mixes are not susceptible to stripping.

In every case, the asphalt in the pavement has hardened with age. However, the author does not feel that this aging is unusual or extreme. The percentage of original penetration retained after aging was compared to similar data from other projects reported in the literature, and the aging rate is no worse, in fact, it is probably less than usual.

Finally, the pavement condition surveys indicate that no unusual wear or pavement distress is present. These pavements are performing quite well.

BIBLIOGRAPHY

1. B. E. Henrikson, "Dryer-Drum Mixing in North Dakota," Paper presented at the Meeting of Flexible Pavements, Incorporated, March, 1975.

2. E. C. Granley, "A FWHA Look at Hot Mix Production Development," Paper presented at the Annual Convention of the National Asphalt Pavement Association, February, 1975.

3. K. E. McConnaughay, Method of Making a Paving Composition, U. S. Patent No. 3,423,222, Jan. 21, 1969.

4. W. L. Allen, Dryer Drum Mixing Process, FWHA Special Report 08-45-B3, April, 1971.

5. J. L. Ziegler, "The Turbulent Mass Process," Paper presented to the National Asphalt Pavement Association, January, 1972.

6. R. L. Terrel and E. S. Richardson, Asphalt Paving Mixtures Produced by the Dryer-Drum Process, Final Report prepared for Federal Highway Administration, August, 1972.

7. E. C. Granley, "The Dryer Drum Process for Producing Bituminous Concrete Mixes," Paper presented to Subcommittee on Construction, AASHO, November, 1972.

8. J. A. Apostolos and G. W. Mann, Evaluation of Asphalt Concrete Produced by the Dryer-Drum Mixing Process, Division of Construction and Research Transportation Laboratory Research Report, Interim Report CA-DOT-TL-3125-1-74-16, November, 1974.

9. Asphalt Institute, Mix Design Methods for Asphalt Concrete, Manual Series No. 2, March, 1974.

10. R. N. Traxler and M. D. Shelby, "Reduction of Asphalt Hardening in Survace Courses of Bituminous Pavements," Proceedings of the Association of Asphalt Paving Technologists, Vol. 42 (1973), p. 147.

11. W. K. Parr and P. J. Serafin, "Four Years Test Trends on the Michigan Bituminous Experimental Road," Proceedings of the Association of Asphalt Paving Technologists, Vol. 28 (1959), p. 297.

12. R. L. LeClerc and T. R. Marshall, "A Pavement Condition Survey Rating System and its Use," Proceedings of the Association of Asphalt Paving Technologists, Vol. 38 (1969), 280-292.

APPENDICES

Table 2. Comparison of Gradation of Mean of Mix Samples with Project Specifications, Nome, Airport.

Sieve Size	Specification Percent Passing	Mean of Mix Samples Percent Passing
3/4"	100	99.5
1/2"	82-96	85.8
3/8"	75-90	79.4
#4	60-73	64.4
#10	43-57	51.4
#40	19-33	21.7
#80	10-20	12.7
#200	3-6	6.9

Table 3. Comparison of Gradation of Mean of Mix Samples with Project Specifications, Safford-Springerville Highway, Arizona.

Sieve Size	Specification Percent Passing	Mean of Mix Samples Percent Passing
1"	100	100.
3/4"	89-99	97.4
1/2"	68-78	78.8
3/8"	87-67	64.5
#4	41-51	43.6
#8	30-38	31.3
#40	11-19	14.5
#200	4-8	5.5

Table 4. Comparison of Gradation of Mean of Mix Samples with Project Specifications, Estacada-Eagle Creek, Oregon.

Sieve Size Passing		Sieve Size Retained	Specification Percent	Mean of Mix Samples Percent
3/4"	-	1/4"	36 ± 4	36.7
1/4"	-	#10	31.3 ± 4	27.0
#10	-	#200	27.1 ± 4	30.4

Table 5. Comparison of Gradation of Mean of Mix Samples with Project Specifications, State Route ONE, Lakota, North Dakota.

Sieve Size	Specification Percent Passing	Mean of Mix Samples Percent Passing
5/8"	100	100.
#4	40-70	68.
#8	50-60	54.
#16	22-50	41.
#30	15-41	28.
#50	10-30	18.
#100	6-20	12.
#200	4-10	10.

Table 6. Crack Count taken on June, 1975 on State Route ONE, Lakota, North Dakota.

Station	Number of Cracks Counted	Cracks per Lane - Mile	Penetration of Asphalt Used
276 + 50	500' North-15 ea. 500' South-16 ea.	164	200 - 300
404 + 20	500' North-19 ea. 500' South-42 ea.	222	120 - 150

Table 7. Comparison of Original and Aged Penetration Values for all Projects.

Site	Age (months)	Average Recovered Penetration at 77°F in 1975	Original Penetration	Percent Decrease in Penetration	Percent of Original Penetration
Alaska	24	51	120-150	--	--
Arizona	22	52	99	47	53
Oregon	32	78	125	38	62
North Dakota	36	77	130	41	59
North Dakota	36	233	252	--	--
North Dakota	28	114	252	55	45

Table 8. Summary of Results of Laboratory Tests Conducted on Material from Pavement Cores Obtained from Four Early Drum Mixer Projects in the United States.

Project and Location	Age at Sampling (months)	Present Marshall Stability of the A.C. (pounds)	Percent of Design Stability	Percent of Stability Retained after 24 Hour Immersion	Original Penetration at 77°F	Penetration after Mixing	Recovered Penetration	Percent of Original Penetration Retained	Road Rating (points)
Nome Airport Nome, Alaska	24	1604	100	86	120-150	--	51	--	--
Safford-Springerville Highway Arizona	22	1409	--	96	99	--	52	53	93
Estacada-Eagle Creek Section of Clackamas Highway Oregon	32	1548	--	100	125	96	78	62	90
Lakota Test Road, North Dakota 120-150 Penetration Section	36	1036	105	100	130	114	77	59	85
200-300 Penetration Section	36	1196	91	100	252	179	--	--	91
200-300 Penetration Section	28	--	--	--	252	179	114	45	--

Table A-1. Data Comparison, Nome Airport

Project: Nome Airport

Location: Nome, Alaska

Parameter	Date and Location of Test				
	1975 U of W			1973 Construction	1973 Job Mix Formula
	26+00	26+00 Bottom Only	48+00	All Stations	
1. Moisture Content	0.47	--	0.9	--	--
2. Bulk Sp. Gr.	232	2.31	2.36	--	--
3. Rice Sp. Gr.	2.45	2.43	2.36	--	--
4. Asphalt Content	5.7	--	6.08	6.05	6.00±25%
5. Recovered PEN. of Asphalt	37	--	79	--	120-150
6. Marshall					
Stability	--	1632	1576	1589	2011
Flow	--	2.9	2.7	--	
7. Marshall Stability after 24 hr. Soak @ 140°F	1286	--	1471	--	--

Table A-2. Asphalt Cement Concrete Core Data

Project: Nome Airport | Date Cored: 19 June 1975

Location: Station 26+00 | Grade Asphalt Used: 120-150

Station	Core No.	% Moisture	Bulk Sp.Gr.	Rice Sp.Gr.	Marshall Stability	Flow	Recovered Asphalt %	Recovered Asphalt Penetration	Stability after 24 hours.
26+00	1B								
	1T								
	2B				1632	2.9	5.7		
	2T						5.7	46	
	3B		2.320	2.439			5.7		
	3T		2.314	2.481			5.7	46	
	4B								
	4T								1286
	5B		2.309	2.427			5.7		
	5T		2.343	2.469					
	6B	0.47							
	6T	0.47					5.9	27	
48+00	1B		2.34	2.45					
	1T		2.37	2.45					
	2B		2.35					79	
	2T				1576	2.6			
	3B		2.35	2.45					
	3T		2.36	2.43			6.04		
	4B								
	4T	0.85							
	5B							79	
	5T				1779	2.8			
	6B								
	6T								1471

Dry Sieve Analysis
Percent Passing

	3/4"	1/2"	3/8"	#4	#8	#40	#80	#200
Station 48+00	100.	90.5	79.7	63.6	53.6	21.8	13.2	7.7
Station 26+00	98.7	94.6	85.3	69.5	57.6	22.0	12.3	7.1

Table A-3. Data Comparison, Arizona

Project: Alpine - Nutrioso

Location: Arizona

Parameter	Date and Location of Sample				
	1975 - U of W August Values		1973 - Ariz. Construction Average	1973 - Final Record Samples Cores	
	1204+00	1256+00	All Stations	1204+00	1256+00
1. Moisture Content	1.45	1.76	--	--	--
2. Bulk Sp. Gr.	2.17	2.17	--	--	--
3. Rice Sp. Gr.	2.47	2.48	--	--	--
4. Marshall					
Stability	1459	1354	--	--	--
Flow	3.5	3.6	--	--	--
5. Recovered Asphalt	6.6	7.0	6.86	6.8	7.1
6. Recovered Asphalt Pen.	52	--	99*	--	--
7. Stability after 24 hr. Soak @ 140°F	1352	1361	--	--	--

*From Circulating Pump Line of Plant - prior to mixing.

Table A-4. Asphalt Concrete Core Data

Project: UNIT I, Alpine-Nutrioso Section, Safford-Springerville Highway

Date Cored: 27 June 1975

Grade Asphalt Used: 85-100

Location: Arizona

Station	Core No.	% Moisture	Bulk Sp.Gr.	Rice Sp.Gr.	%	Recovered Asphalt Pene-tration	Marshall Stability	Flow	Stability after 24 hours.
1204+00	1					53	1456	3.3	
	2						1461	3.6	
	3					51			
	4								1352
	5	1.40	2.175	2.469	6.58				
	6	1.49	2.174	2.463	6.58				
1256+00	1						1367	3.6	
	2	1.67	2.15	2.475	7.02				
	3						1340	3.5	
	4								1296
	5								1425
	6	1.85	2.18	2.475	7.02				

Dry Sieve Analysis

Percent Passing

Location	3/4"	1/2"	3/8"	1/4"	#4	#8	#40	#100	#200
Station 1204+00	97.2	84.4	71.8	56.4	45.9	31.8	14.7	8.9	6.2
Station 1256+00	100.	84.4	69.4	54.6	46.9	33.3	14.7	8.9	6.5

Table A-5. Data Comparison, Oregon

Project: Estacada-Eagle Creek

Location: Oregon

Parameter	Date and Location of Sample					
	1975 - U of W			1972 -Project Construction Data	1972 - November	
	10331	1121	1121 in WP		1033	1121
1. Moisture Content	1.11	1.43	1.12	--	3.2%	2.5%
2. Bulk Sp. Gravity	2.16	2.19	2.32	--	--	--
3. Rice Sp. Gravity	2.433	2.469	2.457	--	--	--
4. Marshall						
Stability	1195	1267	1548	--	--	--
Flow	5.5	4.0	3.2	--	--	--
5. Recovered Asphalt						
Percent	5.9	5.5	5.3	6.1	5.7	6.1
Penetration	--	--	78	96	83 (125)	96 (117)
6. Stability after 24 hrs. @ 140°F	1233	1198	1600	--	--	--

Table A-6. Asphalt Concrete Core Data

Project: Estacada-Eagle Creek — Date Cored: 1 July 1975

Location: Oregon — Grade Asphalt Used: 120-150

Station	Core No.	% Moisture	Bulk Sp.Gr.	Rice Sp.Gr.	Marshall Stability	Flow	Recovered Asphalt %	Recovered Asphalt Penetration	Stability after 24 hours.
1033+00	1								1280
	2								1186
	3				1200	5.9			
	4	1.08	2.15	2.427			5.67		
	5	1.14	2.17	2.439			5.87		
	6				1190	5.0			
1121+00	1								1196
	2				1254	4.4			
	3	1.48	2.19	2.463			5.5		
	4	1.37	2.18	2.475			5.5		
	5								1200
	6				1200	3.5			
1121(WP)	1	1.01	2.32	2.463			5.3		
	2	1.23	2.31	2.451			5.3		
	3				1630	2.9		76	
	4				1466	3.4	5.3		
	5								1600
	6							79	

Dry Sieve Analysis

Percent Passing

Location	3/4"	1/2"	1/4"	#4	#10	#40	#80	#200
Station 1121+00	98.7	90.5	63.9	54.4	35.8	14.8	9.0	6.4
Station 1033+00	98.9	94.	70.4	59.0	39.2	16.2	9.3	7.2

Table A-7. Data Comparison, North Dakota

Project: State Route ONE

Location: North Dakota

Parameter	Date and Location of Sample						
	1975 - U of W		1972-Project Construction		1972-2 hrs. aft. Construction		1974 - Cores taken
	276+00	404+00	All Data		276+00	404+00	All Cores
	200-300	120-150	200-300	120-150	200-300	120-150	200-300
1. Moisture Content	1.7	1.1	1.9	1.6	--	--	1.98
2. Bulk Sp. Gr.	2.246	2.15	--	--	2.24	2.20	2.30
3. Rice Sp. Gr.	2.403	2.38	--	--	--	--	--
4. Marshall							
Stability	1196	1036	1140	1140	--	--	--
Flow	2.9	3.7	1210	120	--	--	--
5. Asphalt Content	6.0	6.2	6.3	6.3	6.4	6.05	5.7 (5.1–6.4)
6. Asphalt Pen.	233	77	189	114	--	--	144
7. Marshall Stability after 24 hr. Soak @ 140°F	1311	1190	--	--	--	--	--

Table A-8. Asphalt Concrete Core Data

Project: F-6-001(02)162 — Date Cored: 25 June 1975

Location: Lakota, North Dakota — Grade Asphalt Used: 120-150; 200-300.

Station	Core No.	% Moisture	Bulk Sp.Gr.	Rice Sp.Gr.	Marshall Stability	Flow	Recovered Asphalt %	Recovered Asphalt Pene-tration	Stability after 24 hours.
404+00*	1								
	2								1190
	3	1.27	2.155	2.392			6.15		
	4				1014	3.45		75	
	5	1.01	2.137	2.370			6.15		
	6				1058	4.0		79	
276+00**	1				1162	2.85	6.0		
	2								1311
	3				1229	2.95		236	
	4	1.82	2.236	2.392			6.0		
	5	1.55	2.257	2.414			6.0		
	6							230	

*120-150 Penetration Asphalt Used
**200-300 Penetration Asphalt Used

Dry Sieve Analysis

Percent Passing

Location	5/8"	#4	#8	#16	#30	#50	#100	#200
Station 404+00	100.	68.1	51.7	34.6	19.5	8.9	3.9	2.6
Station 276+00	100.	65.	49.9	33.8	19.0	10.7	6.8	5.4

Figure B-9. Station 1121+00, Estacada-Eagle Creek, Oregon. Technician stands at edge of raveled surface.

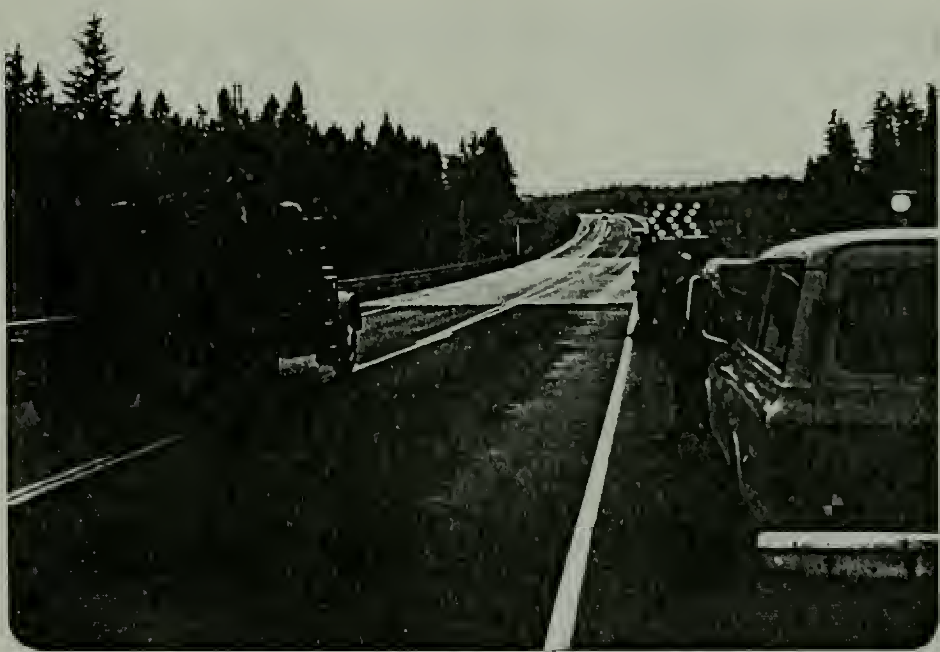


Figure B-10. Station 1033+00. Estacada-Eagle Creek, Oregon.

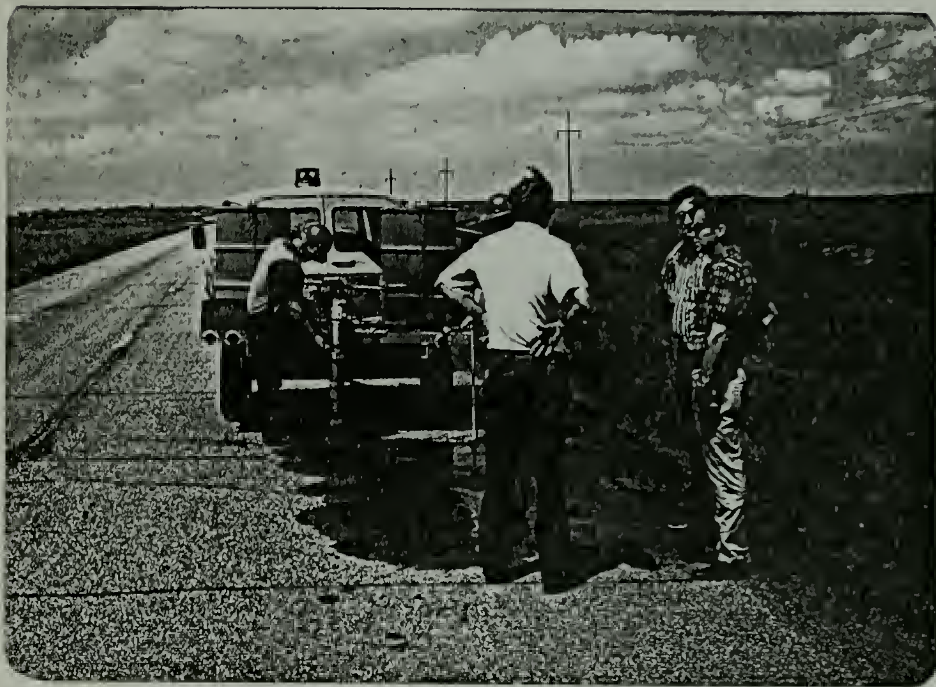


Figure B-11. Section of State Route ONE, Lakota, North Dakota, where 120-150 penetration asphalt was used. Note the frequency of cracking.

Figure B-12. Section of State Route ONE, Lakota, North Dakota, where 200-300 penetration asphalt was used. Compare the frequency of cracking to that in Figure B-11 above.

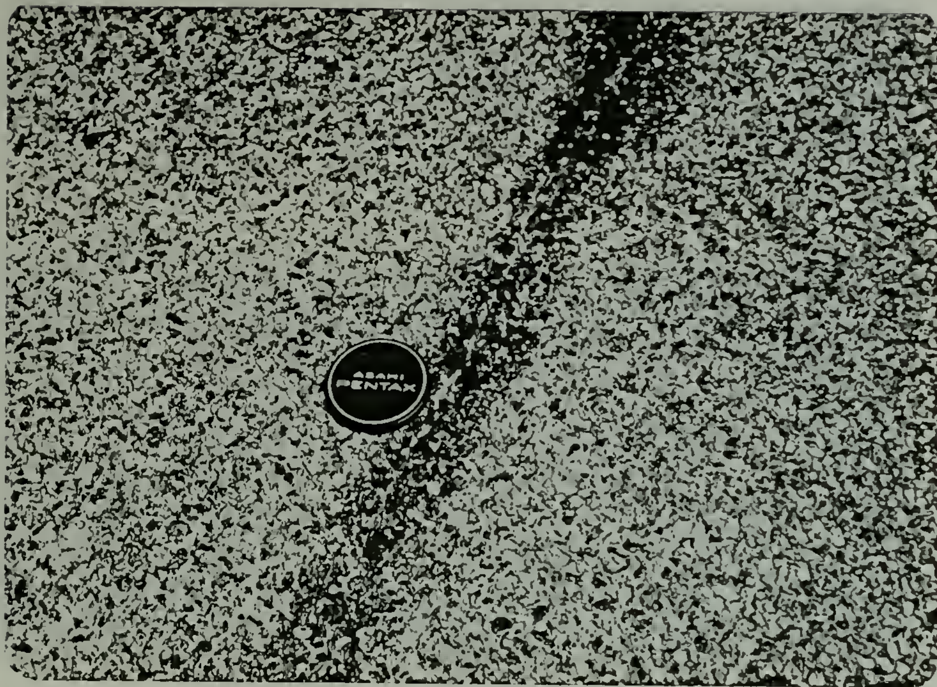


Figure B-13. Closeup of crack in the 200-300 penetration section of State Route ONE, Lakota, North Dakota.

Figure B-14. Station 1204+00, Safford-Springerville Highway, Arizona.

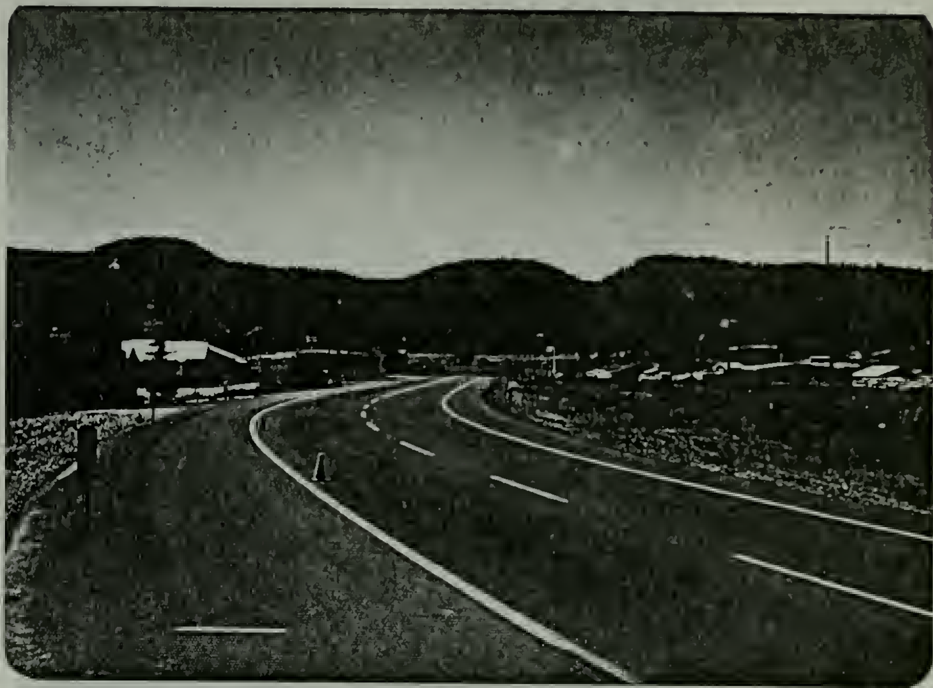


Figure B-15. Station 1256+00, Safford-Springerville Highway, Arizona.

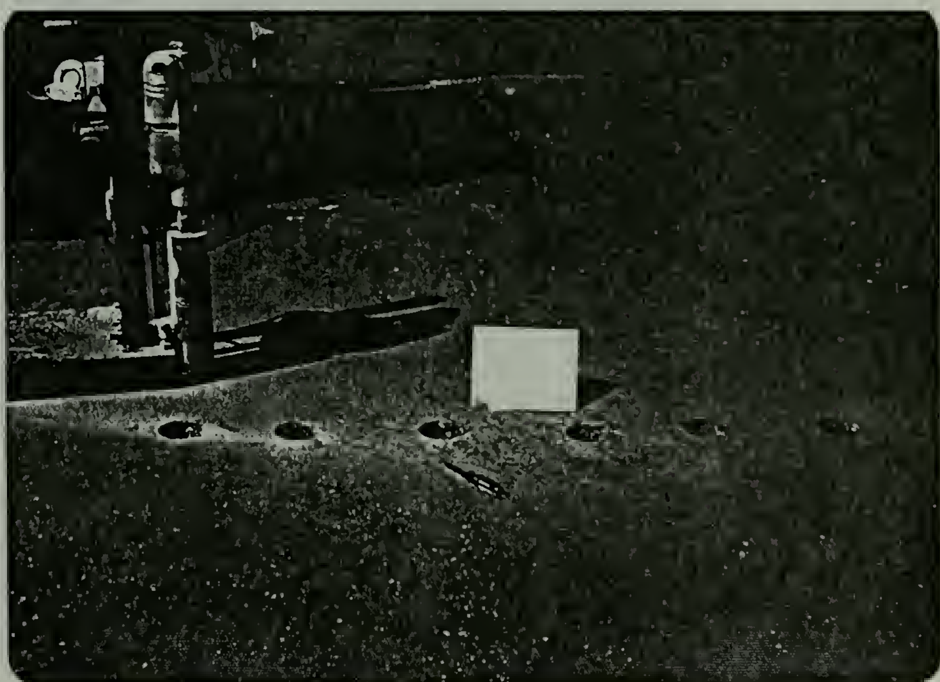


Figure B-16. Station 26+00, Nome Airport, Nome, Alaska. The spacing of these cores is similar to that used on all projects.

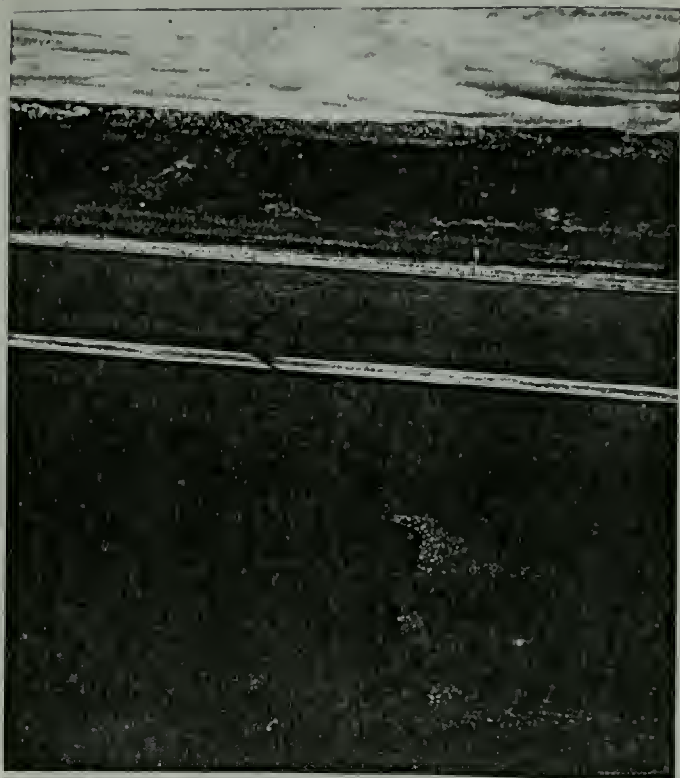


Figure B-17. Thermal crack in East-West Runway, Nome, Alaska, paved in 1973.

Figure B-18. Closeup of thermal crack in Figure B-17 above.

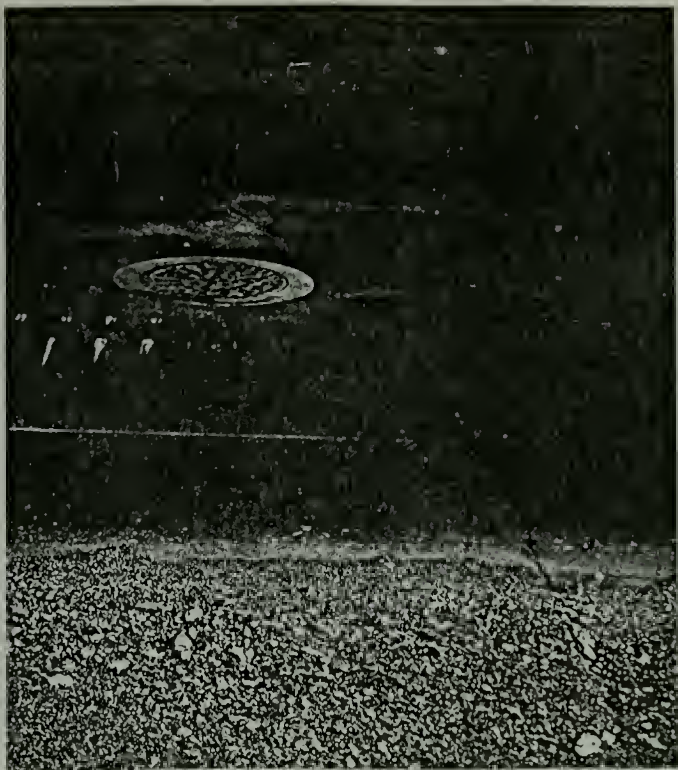


Figure B-19. Reflective crack, East-West Runway, Nome, Alaska.

Figure B-20. Close up of thermal crack in North-South Runway, Nome, Alaska, paved in 1974.

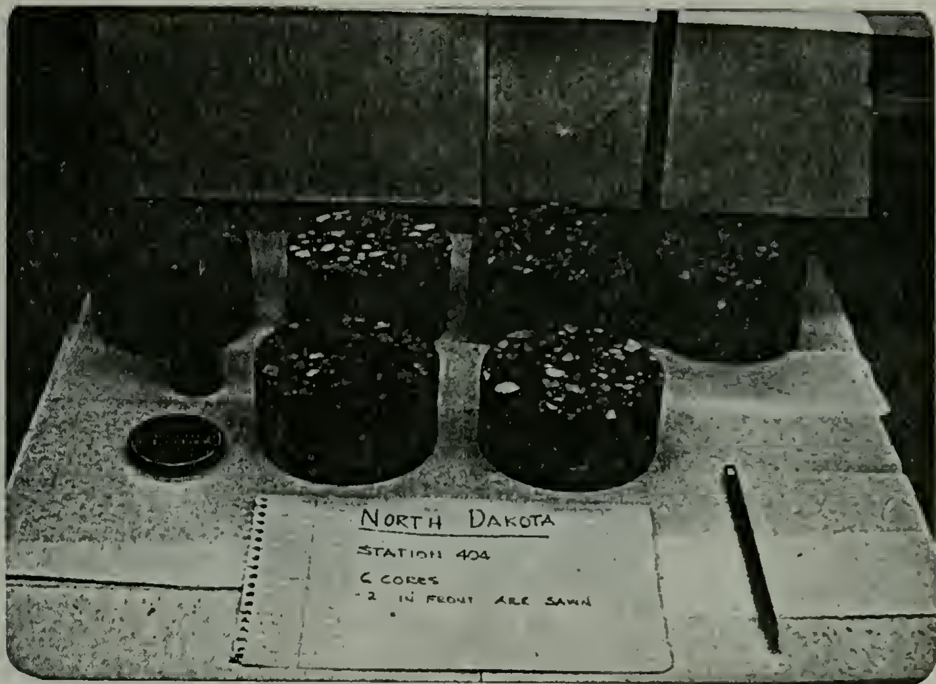


Figure B-21. View of six cores taken from State Route ONE, North Dakota. Cores in foreground have been trimmed for Marshall Stability Tests.

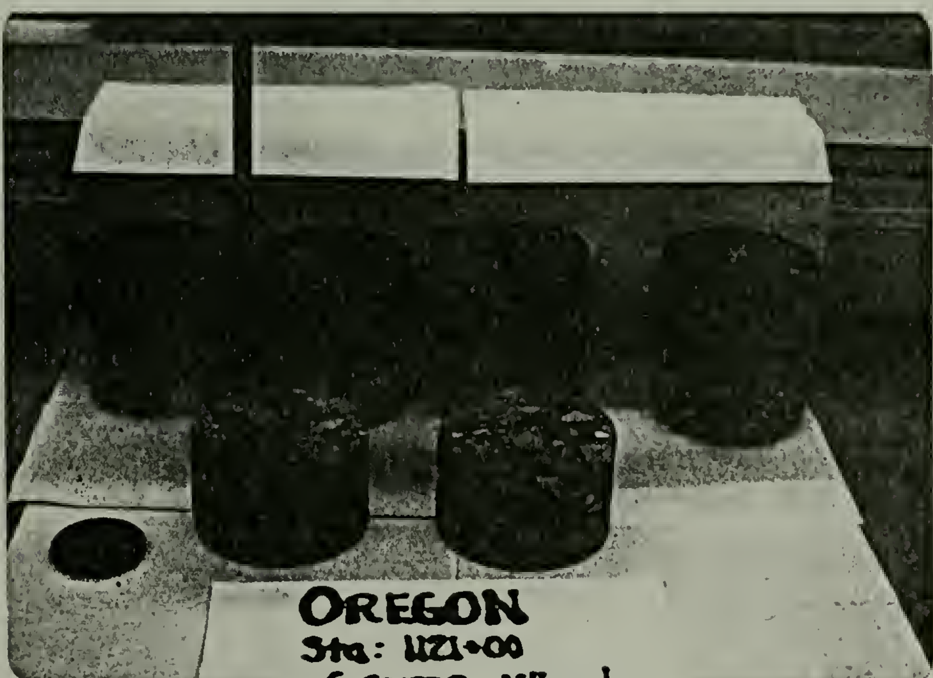


Figure B-22. View of six cores taken from Estacada-Eagle Creek, Oregon.

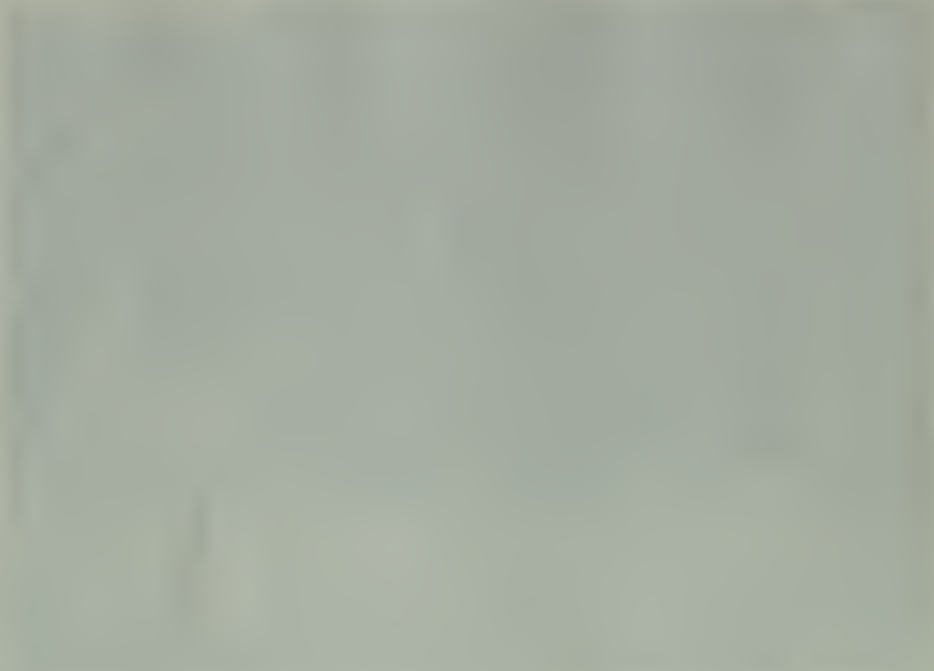
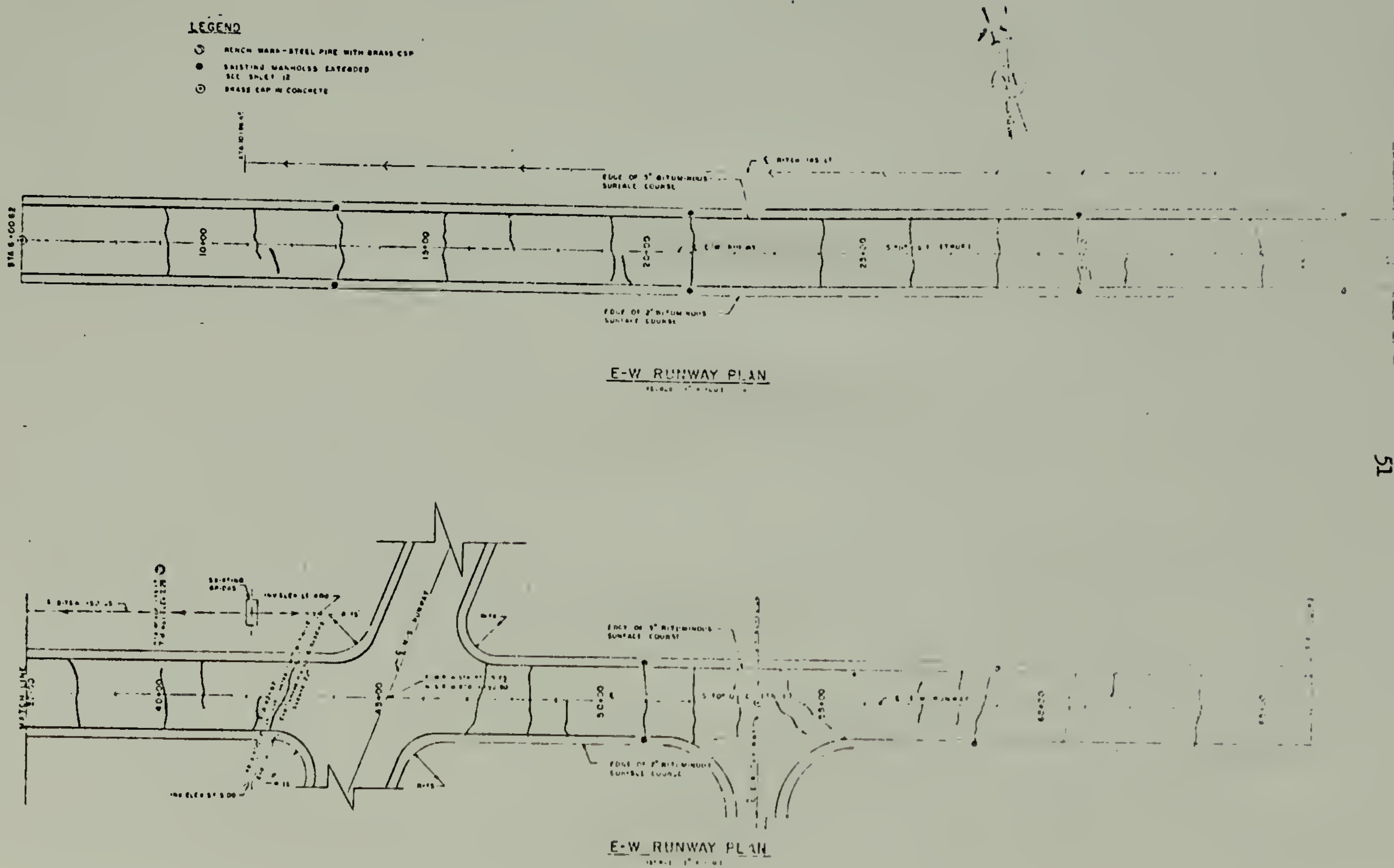


Figure B-23. View of six cores taken from Safford-Springerville Highway, Arizona.

Figure C-24. Crack Patterns, East-West Runway, Nome Airport, Nome, Alaska.



Thesis 102191
H6809 Holen
Performance of asphalt concrete pavements produced by the drum mixer process.